SINGLE SPIN ASYMMETRY IN HIGH P_T CHARGED HADRON PRODUCTION OFF NUCLEI AT 40 GEV

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Abstract

The single transverse spin asymmetry data for the charged hadron production in pC and pCu interactions are presented. The measurements have been performed at FODS-2 experimental setup using 40 GeV/c IHEP polarized proton beam. The hadron transverse momentum range is from 0.5 GeV/c up to 4 GeV/c. The data obtained off the nuclear targets are compared with the proton target data measured earlier with the same experimental setup and with the data of other experiments.

Key-words: spin, asymmetry, hadron production,polarization, quarks, QCD.

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1   Introduction

The experiments performed during the last 25 years show, that the single spin asymmetries in hadron hadron interactions are much larger than expected from the naive pQCD. Also the hyperon transverse polarization is unexpectedly large in collisions of unpolarized hadrons. The pertubative QCD predicts vanishing of single spin effects due to the vector nature of gluons and a small current quark mass. There were no measurements so far of single spin asymmetries of charged hadron production in the energy range between 22 and 200 GeV. We have measured the single-spin asymmetry A_N of the inclusive charged pion, kaon, proton and antiproton production cross sections at high x_T and high x_F for a 40 GeV/c polarized proton beam incident on nuclei (C, Cu), where A_N is defined as

$$A_N = \frac{1}{P_B \cdot cos\phi} \cdot \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}, \tag{1}$$

where P_B is the beam polarization, ϕ is the athimuthal angle of the production plane, $N\uparrow$ and $N\downarrow$ are event rates for the beam spin up and down respectively. The measurements were carried out at IHEP, Protvino in 2003.

2   Polarized beam and experimental setup

The polarized protons are produced by the parity - nonconserving Λ decays [1]. The up or down beam transverse polarization is achieved by the selection of decay protons with angles near 90° in the Λ rest frame by a movable collimator. At the end of the beam line two magnets correct the vertical beam position on the spectrometer target for the two beam polarizations. The intensity of the 40 GeV/c momentum polarized beam on the spectrometer target is 3×10^7 ppp, $\Delta p/p = \pm 4.5\%$, the transverse polarization is 39^{+1}_{-3} %, and the polarization direction is changed each 18 min during 30 s. The beam intensity and the position are measured by ionization chambers and scintillation hodoscopes.

Two Cherenkov counters identify the beam particle composition to control the background contamination. At the spectrometer magnet entrance there are two scintillation hodoscopes to measure the vertical coordinates of the particles emitted from the target.

The measurements have been carried out with the FODS-2 [1] spectrometer. It consists of an analyzing magnet, drift chambers, the Cherenkov radiation spectrometer (SCOCH) for the particle identification ($\pi^\pm$, $K^\pm$, p and $\bar{p}$), the scintillation counters, and the hadron calorimeters to trigger on the high energy hadrons. Inside the magnet there is also a beam dump made of tungsten and copper. There are two arms which can be rotated around the target center situated in front of the magnet to change the secondary particle angle. The Cherenkov radiation spectrometer consists of a spherical mirror with the diameter 110 cm, 24 cylindrical lenses to focus the Cherenkov light on the hodoscope photomultipliers. Measuring the particle velocity using the SCOCH and its momentum in the magnetic field one can determine the particle square mass M^2 (Fig. 1). The SCOCHs are filled with Freon 13 at 8 atm.

There are two threshold Cherenkov counters using air at the atmospheric pressure inserted in the magnet which are used for further improvement of particle identification.
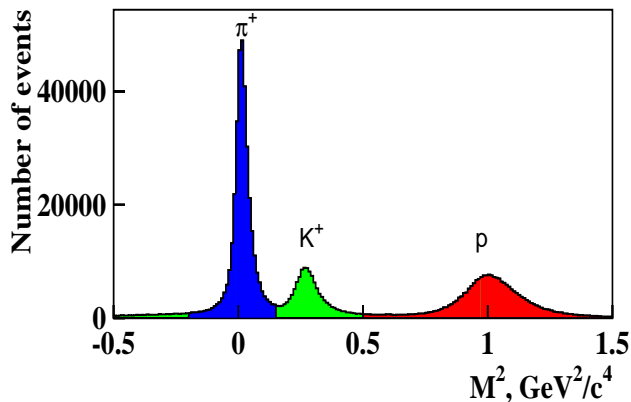
Figure 1: Reconstructed hadron mass squared M^2 in the SCOCH spectrometer.

3 Measurements

In 1994 the study of the single spin asymmetry (A_N) in the inclusive charge hadron production was started using FODS-2:

$$p\uparrow + p(A) \rightarrow h^{\pm} + X, \tag{2}$$

$$p\uparrow + p(A) \rightarrow h^{\pm} + h^{\pm} + X, \tag{3}$$

where $h^{\pm}$ is a charged hadron (pion, kaon, proton or antiproton). The experimental program consists of measuring the charge hadron single spin asymmetry at high x_T and x_F in pp and pA collisions to study the asymmetry dependence on the quark flavors u, d, s and kinematical variables.

The pilot measurements of A_N for the charged hadrons carried out in 1994 with a hydrogen target for small x_F [1] are presented below for the comparison with the data obtained with nuclei. The data for large $x_F \leq 0.7$ were also measured in 2003.

The measurements of A_N in the range $-0.15 \leq x_F \leq 0.2$ and $0.5 \leq p_T \leq 4$ GeV/c are carried out with symmetrical arm positions at angles of $\pm$ 160 mrad. The results for the two arms and the different values of magnetic field in the spectrometer are averaged, which partially cancels systematical uncertainties connected with the variation of the beam position in the vertical direction, the intensity monitor and the apparatus drift.

4 Results

The analyzing power results for six types of hadrons are shown in Fig. 2. The errors quoted are statistical ones. This report presents the first data measured with two different nuclear targets. There were no data so far for charged hadrons with $p_T \geq 2.2$ GeV/c.

In Fig. 2a the π^+ meson production asymmetry is shown. Within the errors there is no difference of A_N for both targets (C and Cu). A_N for the nuclear targets in the range $1 \leq p_T \leq 2$ GeV/c is approximately 4% higher than for the hydrogen target. For the central region such a difference can be connected with the smaller portion of u quarks in the nuclear target containing neutrons. Fragmentation of u quarks (u $\rightarrow \pi^+$)

from the polarized beam protons as well as u quarks of the target contribute to the asymmetry. Because the target protons are not polarized their contribution in the central region reduces the measured polarization. For nuclear targets containing less u quarks in comparison with d quarks the decrease of the asymmetry is not so substantial. Quark scattering in nuclei must also lead to the decrease of the asymmetry due to the p_T shift.

The asymmetry for π^- meson production is presented in Fig. 2b. In the range $0.9 \leq p_T \leq 1.6$ GeV/c it is about 4% higher for the nuclear targets than for the hydrogen target. For the central region such differences can be connected to the larger proportion of d quarks in the nuclear targets. The major contribution give d quarks (d $\rightarrow \pi^-$ fragmentation) from the polarized beam protons and the target. For π^- mesons in pp collisions the asymmetry is therefore negative. Due to the large contribution of the unpolarized target in the central regions the asymmetry for nuclear targets is shifted into the positive region.

Fig. 2c shows the asymmetry for K$^+$ production. There is no significant difference in A_N for the two nuclear targets (C and Cu) and A_N is about 3% higher than for the hydrogen target. The reason of that can be the same as for π^+ mesons.

In Fig. 2d A_N for K$^-$ mesons is presented. Within the errors there is no appreciable difference in A_N for all targets (p, C and Cu) and A_N is close to zero. This is expected because K$^-$ does not contain valence quarks from the polarized beam proton.

In Fig. 2e the asymmetry for the proton production is shown which is close to zero for nuclear targets. For the hydrogen target it is slightly negative.

The asymmetry for antiproton production presented in Fig. 2f shows no difference for all targets (p, C and Cu) and is close to zero. This result is expected because the produced antiproton does not contain valence quarks from the beam proton. Sea quarks in the most models are expected to be unpolarized. The absolute values of analyzing power for antiprotons and K$^-$ mesons may be used as an estimate of systematic bias ($\sim 4\%$) in the data in general.

5   Discussion

It is instructive to compare 40 GeV/c data with the other data. There are very detailed ANL measurements performed at 11.75 GeV/c [2]. There is a similarity in p_T dependence of the analyzing power for negative pions at 40 GeV/c (Fig. 2b) and 11.75 GeV/c (Fig. 3).

In particular, the A_N is rising with p_T, and then dropping back to zero or even negative values. The typical p_T values of maximum and minimum positions are increasing with the beam energy.

Another interesting similarity is between p_T dependence of the positive pion analyzing power (Fig. 2a) and the Λ hyperon polarization in Σ^- Carbon interactions [3]. In Fig. 4 a change-over in p_T dependence is seen. Such behaviour has never been observed before in single spin effects for high energy inclusive reactions.

6   Conclusion

The analyzing powers were measured for $-0.15 \leq x_F \leq 0.2$ and $0.5 \leq p_T \leq 4$ GeV/c in inclusive charged hadron production off carbon and copper with 40 GeV/c polarized

proton beam. Three features of the results can be stressed:

(a) there is no significant difference for the two nuclear targets (C, Cu);

(b) for the positive charge mesons the asymmetry has a maximum at $p_T = 2.2$ GeV/c and decreases to zero at $p_T = 2.9$ GeV/c;

(c) for hadrons not containing valence quarks from polarized protons (K$^-$ and $\bar{\mathrm{p}}$) the analyzing power is close to zero.

The analysis of high x_F data measured in 2003 is still under way.

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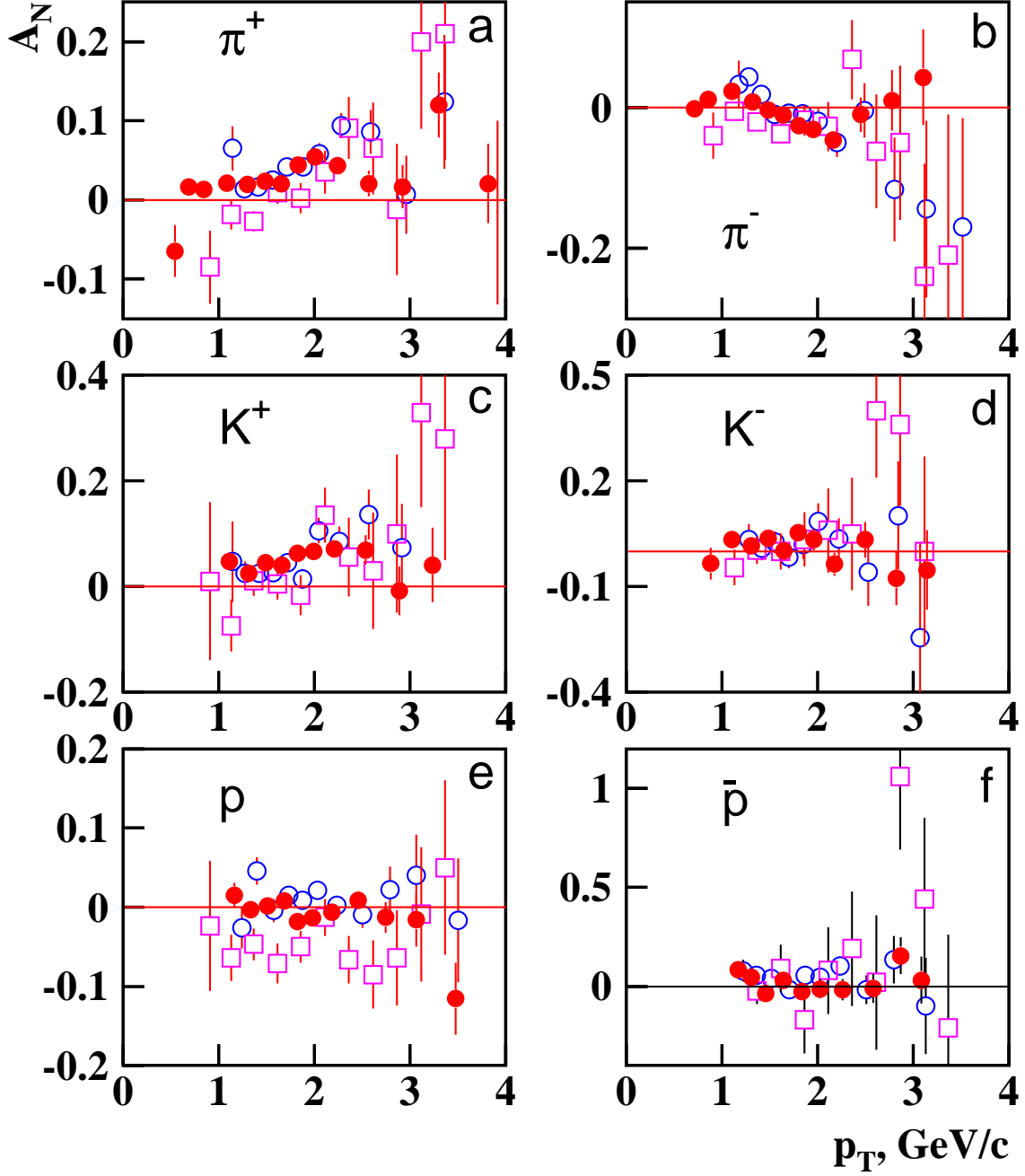[3] M.I. Adamovich *et al.*, *Eur. Phys. J.* **C36**, 315 (2004).

Figure 2: A_N dependence on p_T for $p\!\uparrow +p(A) \rightarrow h^{\pm} + X$, where $h = \pi^+$ (a), π^- (b), K^+ (c), K^- (d), p (e), $\bar{p}$ (f). Closed cirles correspond to C target, open cirles - Cu, square - proton.
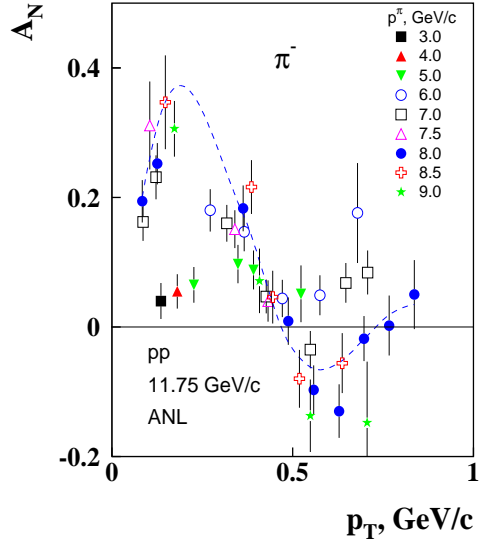
Figure 3: A_N dependence on p_T for $p\uparrow +p \rightarrow \pi^- + X$ [2]. Different symbols correspond to different secondary pion momenta.
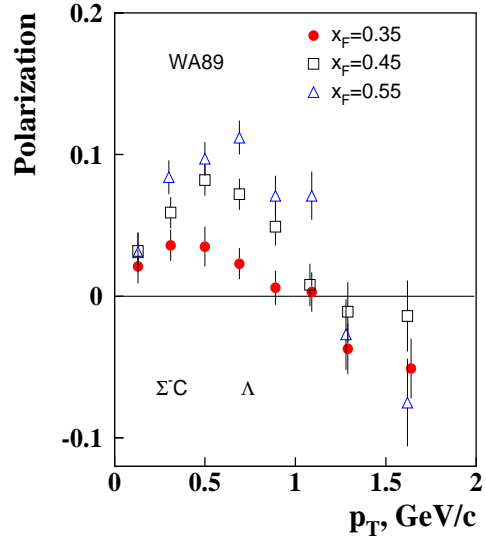

Figure 4: Polarization dependence on p_T for $\Sigma^- + C \rightarrow \Lambda + X$ [3]. Closed cirles correspond to $x_F = 0.35$, open cirles - $x_F = 0.45$, square - $x_F = 0.55$.